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STRESS-RELIEF HEAT TREATMENT OF MANGANESE-NICKEL-ALUMINUM BRONZE AND MANGANESE-BRONZE WELDMENTS

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Tensile properties, weldability, general corrosion, and corrosion-fatigue properties were determined as a function of stress-relief heat treatment for both cast Mn-Ni-Al bronze and manganese-bronze propeller alloys. It was found that Mn-Ni-Al bronze is susceptible to stress-corrosion cracking in the as-welded heat-affected zone. Stress-relief heat treatments in

PRICES SUBJECT TO CHANGE (Cont)

20. ABSTRACT (Cont)

the range of 700° to 1200° F were effective in eliminating the stress-corrosion cracking in this alloy. Manganese-bronze weldments exhibited poor weldability but were not found susceptible to stress-corrosion cracking. High-cycle corrosion-fatigue tests on weldments revealed an endurance strength at 10^8 cycles of 12,000 pounds per square inch for Mn-Ni-Al bronze and 7,500 to 11,000 pounds per square inch for manganese bronze.

(Author)

ADMINISTRATIVE INFORMATION

This work was performed under Work Unit 2823-110, Propeller Alloy Fabrication. The program manager for this work was Mr. B. B. Rosenbaum, NAVSEA (SEA 03523); and the technical agent was Mr. F. D. Rosenthal, NAVSEC (SEC 6101D).

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BACKGROUND

The weld repair of ship propellers is common shipyard practice in view of the high cost of new propeller procurement. Repair operations may vary from localized patching of corrosion damaged areas to the installation of entire propeller blade tips. Regardless of the extent of the welding, care is always exercised to prevent the buildup of excessive residual stress in the weld zone. These stresses may lead to accelerated corrosion attack, resulting in reduced propeller efficiency or even failure. Consequently, propeller alloys known to be susceptible to stress-corrosion cracking are postweld heat-treated as added assurance against excessive residual stresses in the weld zone.

Manganese bronze is reported to exhibit some susceptibility to stress-corrosion cracking. For this reason, current propeller repair specifications require postweld stress-relief treatment for this alloy.[1,2] Another propeller alloy used extensively in the Fleet is Mn-Ni-Al bronze. It has been reported that weldments of this alloy may also be susceptible to stress-corrosion cracking.[3] However, Navy specifications have not required postweld stress-relief heat treatment.

A sharp increase in the number of failures of manganese-bronze and Mn-Ni-Al bronze propellers over the last several years prompted a reexamination of the material and fabrication technology of these alloys. In this connection, the Center was tasked to investigate the effects of postweld heat treatment on the mechanical properties and corrosion resistance of both manganese bronze and Mn-Ni-Al bronze. This report presents the results of the investigation and includes evaluation of mechanical and corrosion-fatigue properties, and general and stress-corrosion resistance as affected by postweld stress-relief heat treatment.

INVESTIGATION

MATERIALS

Both Mn-Ni-Al bronze and manganese-bronze alloys were obtained in the form of 13- x 13- x 2 1/2-inch cast plates. The chemical composition of the plates is listed in table 1. The Mn-Ni-Al bronze plates, conforming to the requirements of specification MIL-B-21230A, alloy 2, were poured from a single heat. Defects in several manganese-bronze plates required that two heats be poured to produce sufficient castings. Both heats conformed to the requirements of specification QQ-B-726E, class A.

[1]Superscripts refer to similarly numbered entries in the Technical References at the end of the text.

TABLE 1
CHEMICAL COMPOSITION OF MANGANESE-BRONZE AND Mn-Ni-Al BRONZE PROPELLER ALLOYS

Alloy	Chemical Composition, %								Zinc Equivalence(1)
	Cu	Mn	Ni	Fe	Al	Sn	Pb	Zn	
				Mn-Ni-Al Bronze					
MIL-B-21230A Alloy 2	71(2)	11/14	1.5/3.0	2.0/4.0	7.0/8.5	-	0.03(3)	-	-
Test plates	74.98	12.57	2.13	2.53	7.78	-	-	-	-
				Manganese Bronze					
QQ-B-726E	55.0/60.0	1.5(3)	0.5(3)	0.4/2.0	0.5/1.5	1.0(3)	0.4(3)	Balance	-
Test plates									
Heat 1	57.21	0.38	0.05	0.93	1.03	0.13	<0.10	Balance	45.4
Heat 2	56.04	0.40	0.03	0.83	1.11	0.14	<0.01	Balance	46.8

(1) Zinc equivalence = 100 - (100 x %Cu)/(100 + A), where A is algebraic sum of the following zinc replacement factors: tin = +1 x %Sn; aluminum = +5 x %Al; manganese = -0.5 x %Mn; iron = -0.1 x %Fe; lead = 0.0; nickel =-2.3 x %Ni.
(2) Minimum.
(3) Maximum.

It should be noted that castings purchased under the latter specification are not required to meet a zinc equivalence percentage requirement; however, manganese-bronze propellers with a zinc equivalence greater than 45% are not considered suitable for repair by welding.[1,2] The zinc equivalence for the material evaluated herein was as follows: heat 1 = 45.4% and heat 2 = 46.8%. Based on the zinc equivalence criterion, castings from heat 1 and heat 2 should not be weldable.

An alternate criterion for assessing the potential weldability of manganese-bronze is the percentage of alpha phase in the microstructure. Specifically, castings containing more than 20% alpha phase are considered weldable.[1] Heat 1 contained approximately 30% alpha phase. The microstructure of heat 2, however, contained only 5% alpha. To increase the alpha-phase content of heat 2, the manganese-bronze cast plates were heat-treated at 1300° F* for 2 hours and cooled in the furnace. This heat treatment was effective in increasing the alpha content to approximately 25%, a level which conforms to the alpha-phase criterion for weldability.

*Abbreviations used in this text are from the GPO Style Manual, 1973, unless otherwise noted.

WELDMENT PREPARATION

Three weldments each of Mn-Ni-Al bronze and manganese bronze were prepared at the Philadelphia Naval Shipyard according to the parameters listed in table 2.

TABLE 2
PARAMETERS FOR WELDMENT FABRICATION

	Mn-Ni-Al Bronze	Manganese Bronze
Process:	GMA (manual-downhand)	GMA (manual-downhand)
Shield Gas:	Argon (30 ft^3/h)	Helium (150 ft^3/h)
Filler:	Ampcotrode 40 (1/16-inch-diameter)	Ampcotrode 10 (1/16-inch-diameter)
Preheat/ Interpass:	150° F minimum, 300° F maximum	300° F minimum, 600° F maximum
Current Type:	D-C reverse polarity	D-C reverse polarity
Volts:	28	28
Amperes:	270	270
Heat Input Range:	10,900-54,700 J/in.	10,000-89,700 J/in.
Average:	28,730 J/in.	26,530 J/in.

	Chemical Composition, %								
	Cu	Al	Mn	Ni	Fe	Si	Zn	Pb	Other
Ampcotrode 40									
Specified	R	7.0/ 8.0	11.0/ 12.0	2.0/ 3.0	2.0/ 3.0	-	-	-	0.50
Actual	75.83	7.45	11.39	2.34	2.99	-	-	-	<0.001
Ampcotrode 10[1]									
Specified	R	9.0/ 11.0	-	-	1.5	0.10	0.02	0.02	-
Actual	89.37	9.36	-	-	0.95	0.05	0.01	<0.001	-

[1] MIL-E-21659, class: MIL-CAL-A2.
R - Remainder; GMA - Gas metal arc welding.

A double-U butt-joint design was employed for both alloys. After welding, the assemblies wer dye-penetrant inspected, radiographed, and returned to this activity for postweld heat treatment and evaluation.

HEAT TREATMENT

Prior to stress-relief heat treatment, each weldment was cut in half across the weld. One half was utilized for determining as-welded properties. The remaining sections were subjected to the following stress-relief heat treatment schedule:

Mn-Ni-Al Bronze	Manganese Bronze (Furnace Cool)
700° F, 2 hours, air cool	400° F, 75 minutes
1050° F, 2 hours, air cool	600° F, 75 minutes
1200° F, furnace cool to 930° F and air cool	800° F, 75 minutes
	1000° F, 75 minutes

Base metal and transverse-weld tensile specimens, and 3/8-inch-thick transverse-weld side-bend test specimens were removed from both alloys as cast, and in each of the heat-treated conditions.

CORROSION-FATIGUE TESTING

Rotating cantilever beam specimens, shown in figure 1, were used for high-cycle corrosion-fatigue testing. A constant, deadweight load was applied at the end, and the cycle frequency was 1450 c/m for all tests. Failure consisted of complete fracture of the specimen.

Corrosion-fatigue testing of the manganese-bronze specimens was performed in sea water at the Francis L. LaQue Corrosion (FLLC) Laboratory, Wrightsville Beach, North Carolina. All Mn-Ni-Al bronze specimens were tested in Severn River water, which is a brackish estuary water containing 1/3 to 1/6 the salt content of natural sea water, depending upon season and tide. The maximum nominal reversed stress, $S_r = MC/I$, was calculated from the applied deadweight load and the dimension of the specimens.

SEA-WATER CORROSION EXPOSURES

Transverse-weld corrosion test panels, each 10 x 2 1/2 x 1/4 inch, were prepared from both alloys as-welded, and in each stress-relief heat-treated condition. Specimens were immersed for 6 months in sea water flowing at 2-3 ft/s at the FLLC Laboratory. In addition, duplicate stress-corrosion test specimens, each 10 x 1 x 1/8 inch, were machined from both alloys as-welded, and in each heat-treated condition. All specimens were stressed to 100% of yield strength during the exposure by using the fixture shown in figure 2. The outer fiber stress was calculated by the formula: $S = (4 \cdot E \cdot T \cdot D)/L^2$, where S is the outer fiber stress, E is the modulus of elasticity, T is the specimen thickness, D is the deflection, and L is the length of the specimen.

The latter specimens were also immersed in sea water flowing at 2-3 ft/s at the FLLC Laboratory

RESULTS AND DISCUSSION

TENSILE PROPERTIES AND WELDABILITY

Base metal tensile properties of the Mn-Ni-Al bronze alloy are presented in table 3, and indicate that the as-cast properties from the 2 1/2-inch-thick plates were significantly lower than the properties obtained with separately cast bars.

TABLE 3
BASE METAL TENSILE PROPERTIES OF Mn-Ni-Al BRONZE

Condition	Yield Strength(1) lb/in²	Ultimate Tensile Strength lb/in²	Elongation in 2 Inches %
Separately cast control bars	44,000 44,000 44,000(2)	97,000 96,000 96,500	25.0 25.0 25.0
As-cast 2 1/2-inch-thick plate	36,800 37,220 37,010	73,100 77,190 75,145	15.0 18.0 16.5
700° F, 2 hours, air cool	37,590 37,420 37,505	75,690 74,590 75,140	20.0 16.0 18.0
1050° F 2 hours, air cool	35,370 34,090 34,730	84,890 76,690 80,790	37.0 20.0 28.5
1200° F furnace cool to 930° F air cool	35,090 35,590 35,340	80,700 85,210 82,960	27.0 35.0 31.0
Specification MIL-B-21230A, alloy 2	40,000(3)	90,000(3)	20(3)

(1) 0.2% offset yield strength.
(2) Average value.
(3) Minimum required properties.

Although these differences are not unusual, they indicate that separately cast test bars may not give representative tensile properties for thick cast sections. The 700° F heat treatment did not affect as-cast tensile properties. In contrast, heat treatment at 1050° and 1200° F were effective in increasing the base metal tensile strength and ductility, while only slightly decreasing yield strength.

Transverse-weld tensile properties listed in table 4 show that postweld heat treatment did not substantially affect the properties, and specimens in all conditions exhibited greater than 100% joint efficiency, based on the average base metal tensile strength of material in the same heat-treated condition. Transverse-weld side-bend tests were used to assess the weldability of Mn-Ni-Al bronze in each heat-treated condition. All as-welded and heat-treated specimens passed the required bend test around a 4T radius. Thus, it appears that the postweld heat treatments employed herein did not adversely affect the weldability.

TABLE 4

TRANSVERSE-WELD TENSILE PROPERTIES OF Mn-Ni-Al BRONZE

Condition	Yield Strength(1) lb/in²	Ultimate Tensile Strength lb/in²	Tensile Elongation %	Fracture Location
As welded	46,200 48,440 47,320(2)	32,420 88,070 85,240	13.0 19.0 16.0	Base metal Base metal
700° F, 2 hours, air cool	43,730 47,370 45,550	84,210 88,220 86,215	14.0 16.0 15.0	Base metal Base metal
1050° F, 2 hours, air cool	46,700 46,300 46,500	86,410 81,030 83,720	15.0 10.0 12.5	Weld defect Base metal
1200° F, furnace cool to 930° F air cool	45,110 43,760 44,435	86,220 86,030 86,125	27.0 18.0 22.5	HAZ HAZ

(1)0.2% offset yield strength.

(2)Average value.

HAZ - Heat-affected zone.

The base metal and transverse-weld tensile properties of manganese-bronze heat 1 are presented in table 5. It is noted that the tensile properties from the 2 1/2-inch-thick plate were comparable to those obtained with separately cast test bars. The overall effect of the heat treatment at 600° or 1000° F is considered insignificant since all tensile properties exceed minimum specification requirements.

Although heat 1 conformed to the percent alpha-phase criteria for determining weldability, results of transverse-weld tests revealed extensive lack of fusion along the weld-base interface. As a result of this lack of fusion, all transverse-weld side-bend specimens failed to pass even an 8T radius bend. The appearance of the lack-of-fusion defects and the marginal zinc equivalence of heat 1 indicated that this was not a weldable manganese-bronze alloy.

It was noted earlier that heat 2 did not conform to the zinc equivalence or percent alpha-phase weldability criteria and therefore castings from this heat were treated at 1300° F in order to increase the percent alpha phase in the microstructure. Subsequent stress-relief heat treatment at temperatures up to 1000° F did not significantly alter base metal tensile properties within each plate, as shown in table 6.

Transverse-weld tensile tests on specimens from heat 2 weldments listed in table 7 exhibited the same lack-of-fusion defects noted in heat 1 and had correspondingly poor joint efficiencies. Results of side-bend tests verified the poor weldability of heat 2. It was noted that only specimens stress relieved at 400° or 600° F passed the required 6T radius bend. Those treated at 800° and 1000° F failed even the 8T radius bend. The latter results are attributed to excessive lack-of-fusion defects rather than to the effects of postweld heat treatment.

The results of heat 2 indicate that the use of a heat treatment to salvage manganese-bronze propellers which do not conform to the zinc equivalence or alpha-phase weldability criteria may not always be successful. It was noted that the effectiveness of the 1300° F anneal in precipitating alpha phase depended upon the prior microstructure in the region under consideration. Specifically, alpha phase precipitated primarily at beta-phase grain boundaries and at iron-phase particles in the microstructure, as shown in figure 3. Thus, depending upon the grain size and the degree of microsegregation, at a given region in the cast manganese bronze, the extent of alpha phase precipitated during heat treatment may vary considerably.

TABLE 5

TENSILE PROPERTIES OF MANGANESE BRONZE, HEAT 1

Base Metal Condition	0.2% Offset Yield Strength lb/in²	Ultimate Tensile Strength lb/in²	Tensile Elongation %
As-cast, separately cast control bars	28,000 27,000 27,500(1)	78,000 78,000 78,000	30.0 28.5 29.2
As-cast, 2 1/2-inch cast plate	28,070 28,970 24,530 25,810 26,840	78,200 81,920 74,680 76,190 77,750	18.0 21.0 26.6 37.5 25.8
600° F, 75 minutes, furnace cooled	26,570 26,670 26,620	75,690 76,090 75,890	32.8 33.6 33.2
1000° F, 75 minutes, furnace cooled	24,160 24,250 24,200	72,670 72,960 72,810	35.9 39.1 37.5
Federal standard QQ-B-726E class A	-	65,000(2)	20.0(2)

(1) Average value.

(2) Minimum required properties.

Transverse welds	0.2% Offset Yield Strength lb/in²	Ultimate Tensile Strength lb/in²	Tensile Elongation %	Joint Efficiency(1) %	Fracture Location
As welded	33,200 33,830 33,515	54,700 50,125 52,413	3.5 3.0 3.25	70.4 64.5 67.4	Fusion line Fusion line

(1) Based on base metal tensile strength in the same condition.

TABLE 6
BASE METAL TENSILE PROPERTIES OF MANGANESE BRONZE, HEAT 2

Condition(1)	Plate	0.2% Offset Yield Strength lb/in²	Ultimate Tensile Strength lb/in²	Tensile Elongation %
Separately cast test bars	-	27,000 28,000 27,500(2)	80,000 82,000 81,000	20.0 20.0 20.0
2 1/2-inch-thick plate casting, 400° F, 75 minutes, furnace cooled	A	21,730 22,480 22,100	69,430 70,930 70,180	32.0 36.0 34.0
600° F, 75 minutes, furnace cooled	B	25,730 26,070 25,900	75,090 76,690 76,390	21.0 28.0 24.5
800° F, 75 minutes, furnace cooled	B	24,980 26,070 25,520	80,420 80,200 80,310	30.0 31.0 30.5
1000° F, 75 minutes, furnace cooled	A	23,150 23,350 23,250	72,470 72,430 72,450	37.0 37.0 37.0

(1) Plates A and B were heat treated first at 1300° F (2 hours, furnace cooled) to increase the alpha-phase content of their microstructures.

(2) Average value.

TABLE 7

TRANSVERSE-WELD TENSILE PROPERTIES OF MANGANESE BRONZE, HEAT 2

Condition(1)	Plate	0.2% Offset Yield Strength lb/in²	Ultimate Tensile Strength lb/in²	Tensile Elongation %	Joint Efficiency(2) %	Fracture Location
400° F, 75 minutes, furnace cooled	A	30,460 - (3) 30,460(4)	72,600 - 72,600	9.0 - 9.0	100 - 100	Base-HAZ
600° F, 75 minutes, furnace cooled	B	29,970 34,090 32,030	39.960 66,430 53,200	2.0 6.0 4.0	52.3 87.0 70.0	Fusion line
800° F, 75 minutes, furnace cooled	B	32,580 29,720 31,150	68,170 61,940 65,060	5.0 5.0 5.0	84.4 77.1 81.0	Fusion line
1000° F, 75 minutes, furnace cooled	A	27,720 25,850 26,785	57,940 53,950 55,940	4.5 4.0 4.2	80.0 74.5 77.2	Fusion line

(1)Plates A and B were heat treated at 1300° F (2 hours, furnace cooled) prior to welding.
(2)Based upon base metal tensile strength in the same condition.
(3)Specimen not tested due to defect.
(4)Average value.

SEA-WATER CORROSION EXPOSURES

After 6 months in flowing sea water, as-welded Mn-Ni-Al specimens exhibited heat-affected zone cracks. It was also noted that the as-welded specimens showed obvious copper-colored spots in the HAZ, indicating a preferential corrosion in this region. Figure 4 illustrates the surface appearance of an as-welded Mn-Ni-Al bronze specimen and the selective phase corrosion noted in the as-welded HAZ. Specimens which received a postweld heat treatment were generally more resistant to preferential corrosion in the HAZ. The specimens heat treated at 1050° and 1200° F exhibited better overall corrosion resistance than those heat treated at 700° F.

The above observation may be explained by examining the microstructure in the HAZ of the Mn-Ni-Al bronze weldment in each of the conditions tested. As shown in item (a) of figure 5, the as-welded HAZ microstructure contains alpha-phase particles in a continuous matrix of darker etching beta phase. The beta phase is susceptible to both selective phase corrosion and to stress-corrosion cracking. Heat treatment of 700° F, item (b) of figure 5, did not markedly reduce the amount of beta phase, but did produce a fine precipitate within the beta matrix. This phase is a complex Cu-Mn-Al compound which forms on prolonged heating in the temperature range of 600° to 900° F. Heat treatment at 1050° or at 1200° F followed by a furnace cool to 930° F, produced significant amounts of alpha phase in the beta matrix, as shown in items (c) and (d). The presence of large quantities of alpha phase improves the resistance of the HAZ to selective phase corrosion and to stress-corrosion cracking.

The stress-corrosion cracking tests on the Mn-Ni-Al bronze welds yielded results which were similar to those on freely corroding specimens, discussed above. The as-welded specimens which were subjected to yield stress loading during the exposure failed in about 120 days. The specimens cracked in half through the HAZ, as shown in figure 6. None of the stress-relief heat-treated specimens displayed stress-corrosion cracking after a 6-month exposure to sea water under yield stress loading. Thus, it appears that Mn-Ni-Al bronze weldments should be stress-relief heat treated to ensure resistance to stress-corrosion cracking in the as-welded HAZ. Although all the heat-treat cycles used herein were effective in preventing stress-corrosion cracking, it appears that thermal treatment in the range of 1050° to 1200° F imparts the best overall corrosion resistance to the welded material.

Examination of the manganese-bronze sea-water corrosion panels after the 6-month exposure did not reveal any evidence of cracking or preferential corrosion in the HAZ. All corrosion specimens exhibited a uniform spot-like coppering of the base metal, as shown in item (a) of figure 7. Metallographic examination revealed the presence of a subsurface penetrating selective phase corrosion attack on the beta phase (item (b) of figure 7). However, variation in the stress-relief heat treatment temperature did not have a noticeable effect on the corrosion tendencies of these weldments. In contrast to the results on Mn-Ni-Al bronze weldments, none of the stress-corrosion test specimens exhibited cracking after 6 months in sea water. This appears to be consistent with earlier reports on Cu-Zn alloys, which found that all beta-type materials are most susceptible to stress-corrosion cracking. The rather appreciable alpha content of the materials investigated herein (approximately 25%) apparently rendered these materials resistant to stress-corrosion cracking regardless of the specimen condition (i.e., as-welded or postweld heat treated). Although the effectiveness of the stress-relief heat treatment in preventing stress-corrosion cracking was not demonstrated by this work, it is considered advisable that the

requirement for stress-relief treatment at 600° to 800° F be continued for manganese-bronze propellers to ensure against the occurrence of stress-corrosion cracking in material which has marginal alpha-phase contents.

CORROSION-FATIGUE TESTING

Results of corrosion-fatigue tests on the Mn-Ni-Al bronze weldments are presented in figure 8. Since all the testing was performed in Severn River water, item (a) compares the results on weldment to an available S-N curve for base metal also tested in Severn River water, Examination of these data shows that although there is appreciable scatter in the data from welded material, the endurance strength at 10^8 cycles for welded material is approximately 5000 lb/in^2 lower than that of the base metal (i.e., 12 thousand pounds per square inch (ksi) versus 17 ksi base metal). The data plotted in item (b) of figure 8 give an insight into the effect of stress-relief heat treatment on Mn-Ni-Al bronze weldments. It is noted that five out of six as-welded specimens failed in the HAZ, while the stress-relief heat-treated specimens failed predominantly in the weld deposit at gas-porosity defects or in the base metal. These observations appear to verify the results reported above which indicate that postweld thermal treatment is beneficial to the HAZ corrosion resistance of Mn-Ni-Al bronze weldments.

The results of corrosion-fatigue tests on the welded manganese-bronze specimens tested in sea water are plotted in figure 9. Once again, it is noted that there is considerable scatter among the data points and there was no apparent correlation between specimen condition (as-welded versus stress-relief heat treated) and the cycles-to-failure at a given stress level. Most specimens failed in the weld deposit at gas-porosity defects or along the fusion line at lack-of fusion defects.

Upper and lower bounds are indicated in figure 9 for the corrosion fatigue data on the cast manganese-bronze weldments. It appears that the 10^8 cycle endurance strength for these welds lies in the range of 7,500 to 11,000 lb/in^2. Data on base metal corrosion-fatigue performance in sea water was not available for comparison purposes.

CONCLUSION

On the basis of the results of tests performed and the observations reported herein, the following conclusions appear warranted:

- Cast Mn-Ni-Al bronze is susceptible to stress-corrosion cracking in the as-welded heat-affected zone when subjected to yield stress loading in sea water. Stress-relief heat treatment in the range of 700° to 1200° F does not significantly alter transverse-weld or base metal tensile properties, but eliminates the susceptibility to stress-corrosion cracking in the heat-affected zone.

- Stress-relief heat treatment of Mn-Ni-Al bronze weldments at 1050° or at 1200° F imparts the best overall corrosion resistance to the heat-affected zone.

- The corrosion-fatigue endurance strength at 10^8 cycles of Mn-Ni-Al bronze weldments tested in Severn River water is approximately 12,000 lb/in^2. Corrosion fatigue properties of the weldments were consistently lower than those for cast base metal.

- The tensile properties of Mn-Ni-Al bronze base metal measured on specimens from 2 1/2-inch-thick cast plate are significantly lower than tensile properties measured on separately cast test coupons.

- Manganese-bronze weldments are not susceptible to stress-corrosion cracking when subjected to yield stress loading in flowing sea water.

- Stress-relief treatment in the range of 400° to 1000° F does not significantly change the tensile, corrosion-fatigue or general corrosion properties of manganese bronze.

- The endurance strength at 10^8 cycles for manganese-bronze weldments tested in sea water lies in the range of 7,500 to 11,000 lb/in^2.

RECOMMENDATIONS

On the basis of the results reported herein, it is recommended that all weld repair operations on cast Mn-Ni-Al bronze propellers or machinery components exposed to sea water be followed by a stress-relief heat treatment to assure freedom from stress-corrosion cracking in the HAZ of the weldment. Stress-relief temperatures in the range of 700° to 1200° F are effective in eliminating stress-corrosion cracking, but optimum corrosion resistance is attained when heat treatment is performed in the range of 1050° to 1200° F. It is recommended that the current practice of stress-relief heat treating after weld repair of manganese-bronze propellers be continued even though no evidence of stress-corrosion cracking was observed in this investigation.

FUTURE WORK

No additional work is planned on the subject of stress-relief heat treatment of manganese-bronze and Mn-Ni-Al bronze weldments.

TECHNICAL REFERENCES

1 - Guidance Manual for Making Bronze Propeller Repairs, American Bureau of Shipping (1967)
2 - NAVSHIPS Technical Manual 0991-023-300 (June 1965)
3 - Superston Manual, Stone Manganese Marine Ltd. (Sep 1963)

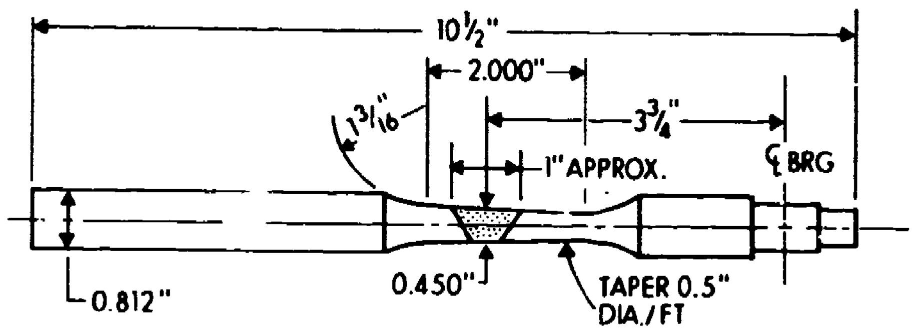

Figure 1
Rotating Cantilever-Beam Corrosion-Fatigue
Test Specimen

$$\text{OUTER FIBER STRESS} = \frac{4E \cdot T \cdot D}{L^2}$$

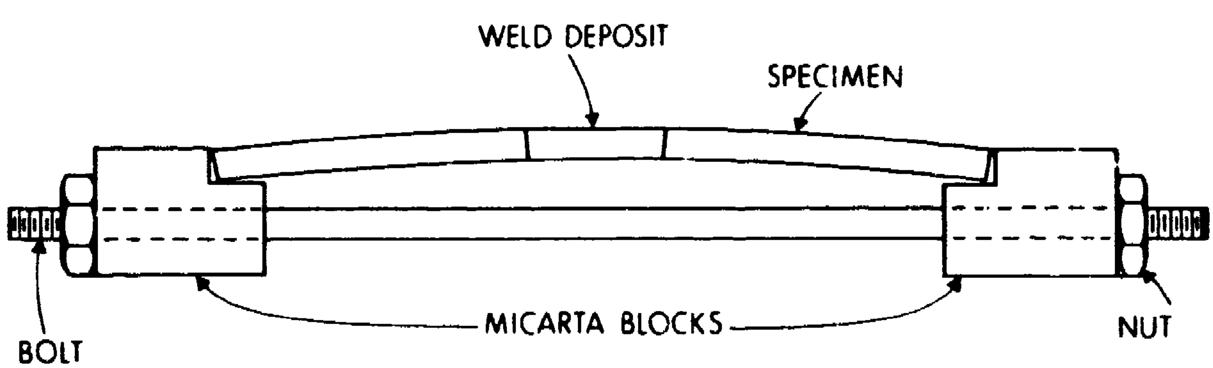

Figure 2
Stress-Corrosion Cracking Test Specimen and Fixture

Item (a)
As-Cast, Less Than 5% Alpha Phase

Item (b)
Annealed 13[illegible] °F (2 Hours)
25-3[illegible] Alpha Phase

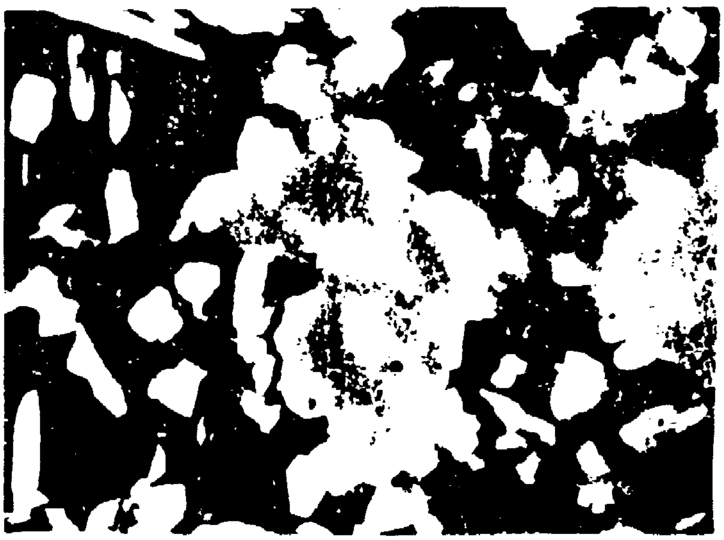

Figure 3
Microstructures of Cast
Manganese-Bronze Base Metal (100X)

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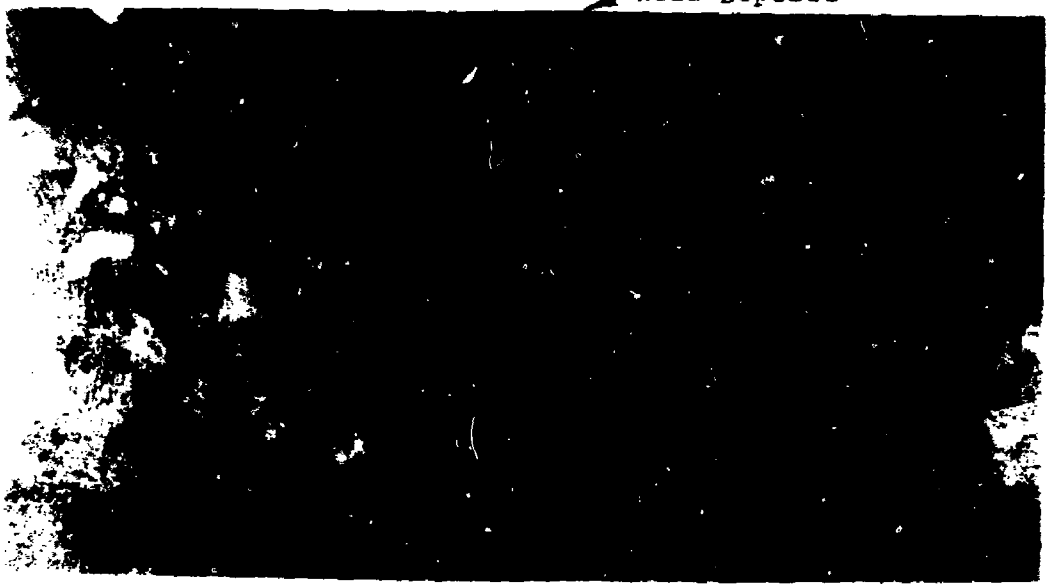
Item (a)
Freely Corroding Specimen (1.5X)
(Light Circular Spots are Copper-Colored)



[illegible]
[illegible] Continuous Phase
[illegible] HAZ [illegible] X

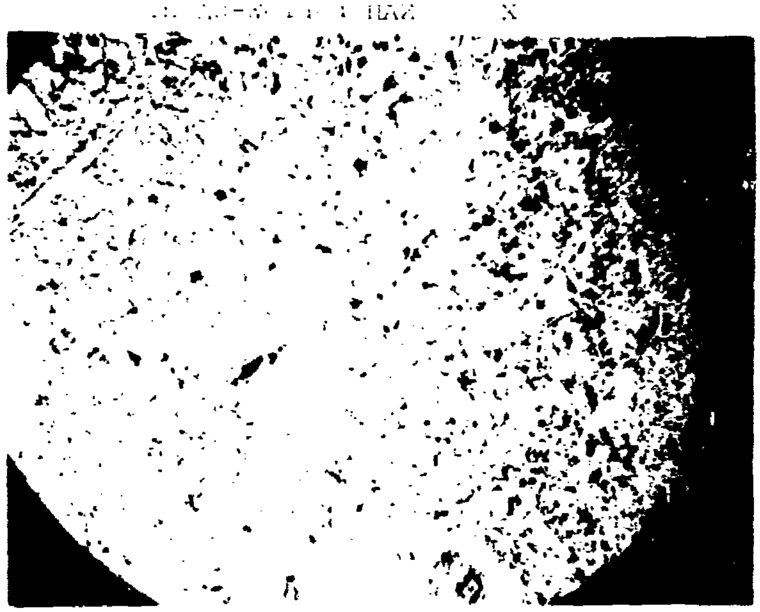
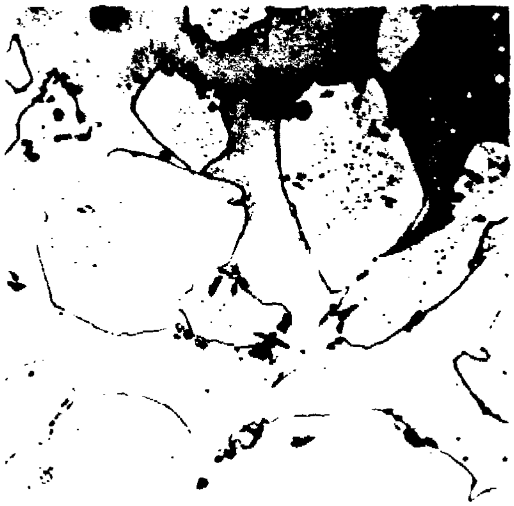


Figure 4
Typical Corrosion Attack on Mn-Ni-Al Bronze Weldments
After a 6-Month Sea-Water Exposure

4447

Item (a)
As-Welded



Item (b)
700° F, 2 Hours
Air Cooled

Item (c)
[illegible]5[illegible] F, 2 Hours
Air Cooled

Item (d)
12[illegible] F Furnace Cooled to
[illegible]3[illegible] F Air Cooled

Figure 5
Heat-Affected Zone Microstructures of
Mn-Ni-Al Bronze Weldments (5[illegible]X)

1 S 1 - B

Figure [illegible]
Stress-Corrosion Cracking in As-Welded
Mn-Ni-Al Bronze Weldment 3X

4447

Item (a)
Freely Corroding Specimen (1.5X)
(Dark Areas are Copper-Colored)

Item (b)
Selective Phase Corrosion on Base Metal (100X)

Figure 7
Typical Corrosion Attack on Manganese-Bronze Weldments
After a 6-Month Sea-Water Exposure

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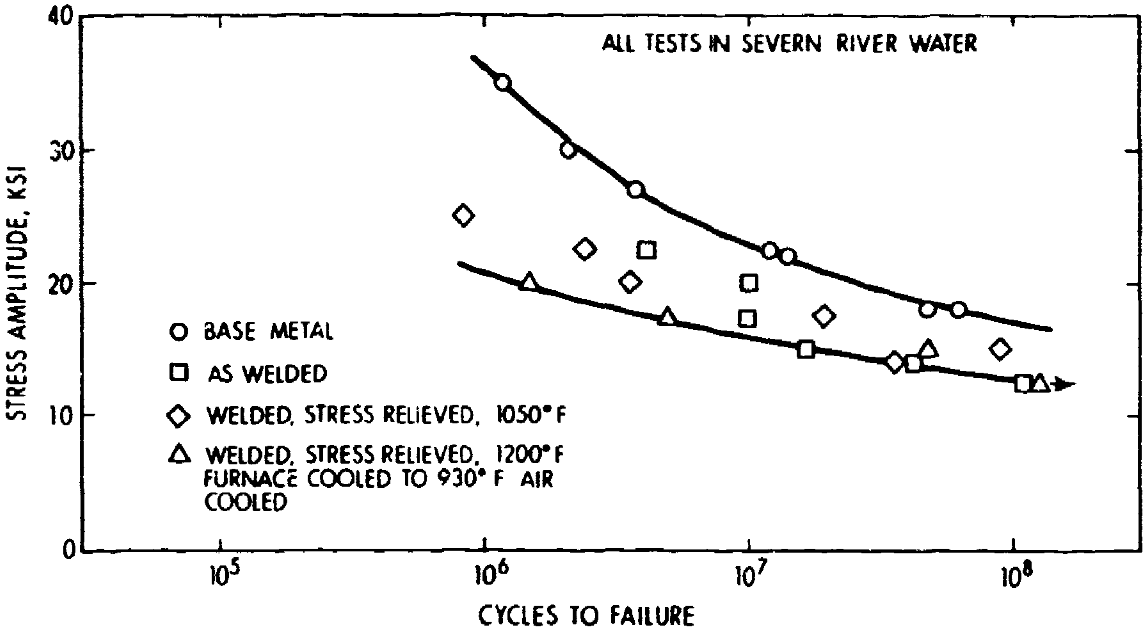
Item (a) - Corrosion-Fatigue Results



Item (b) - Fracture Location

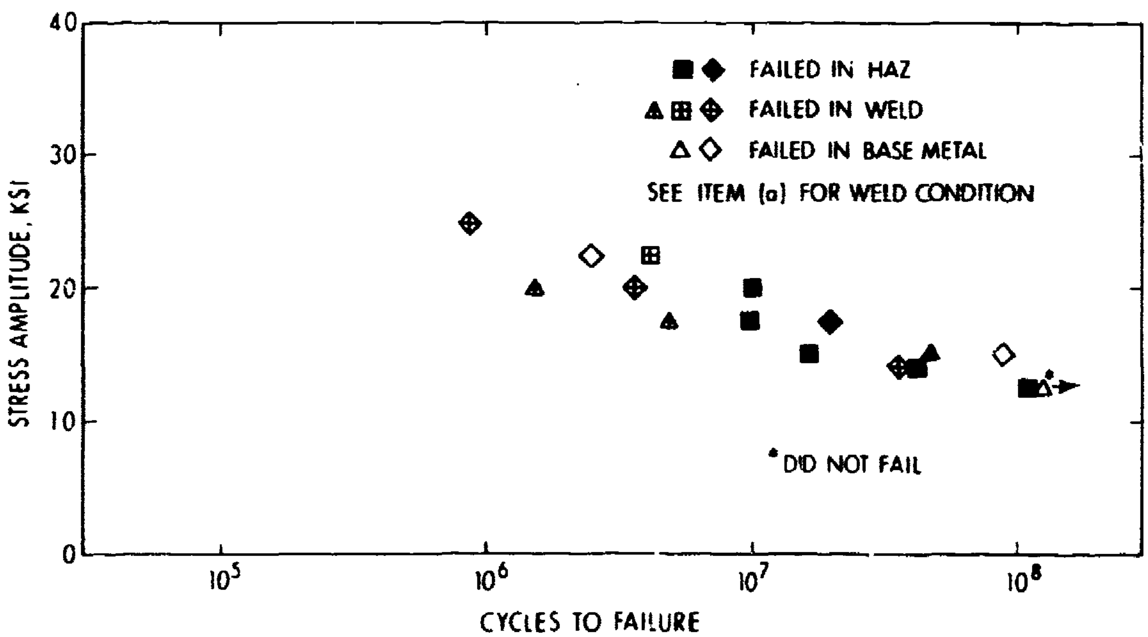


Figure 8
Results of Corrosion-Fatigue Tests on
Mn-Ni-Al Bronze Weldments

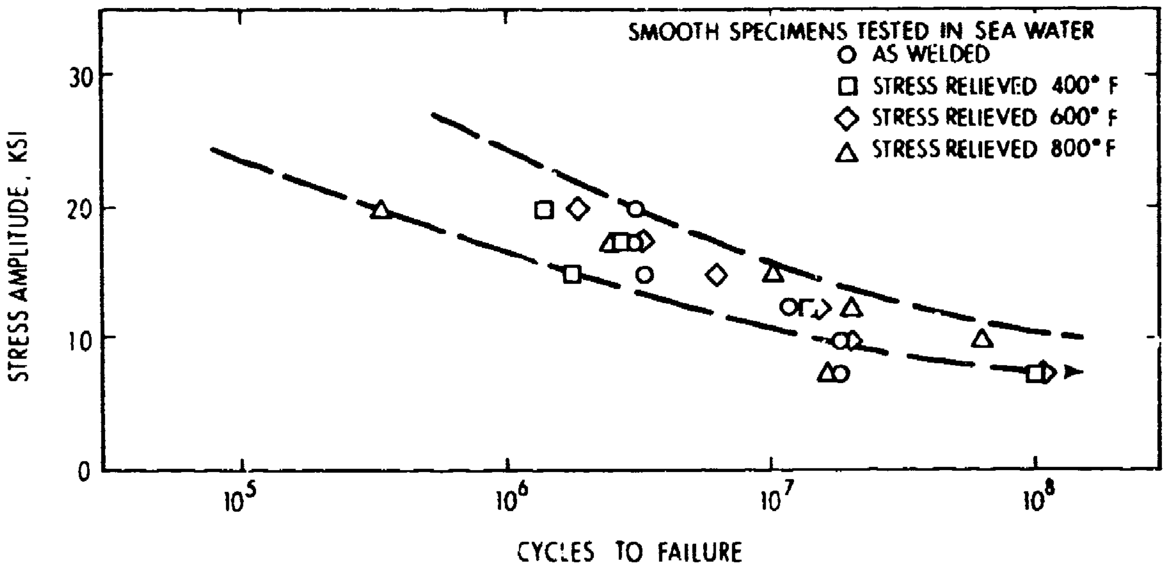


Figure 9
Results of Corrosion-Fatigue Tests on
Manganese-Bronze Weldments

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